4. SAFETY ANALYSIS

LANSCE represents a mature technology with largely well-understood hazards. The safety analysis focused on hazards with significant consequences if barriers fail. Table 4-1gives a generic list of hazards and the kinds of barriers implemented at LANSCE.

4.1 SAFETY ANALYSIS METHODOLOGY

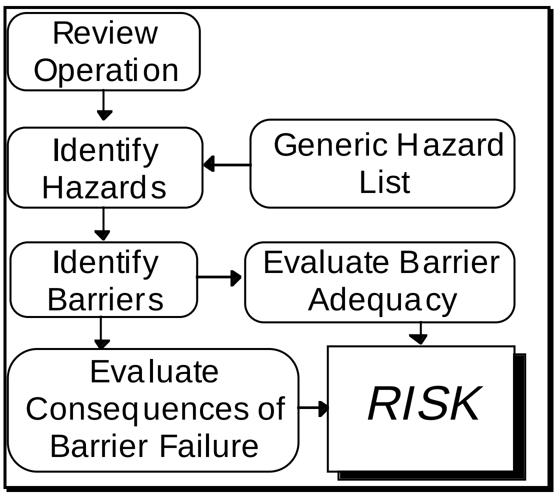

Figure 4-1. Safety Analysis Methodology.

The methodology used to perform the safety analysis is shown in Figure 4-1. The analysis began with a systematic screening of operations against generic hazards list to identify hazards present and the barriers, controls, and mitigating factors used to manage the risk.

Then the adequacy of the barriers was reviewed, based upon (first preference) established standards and practices as shown in Table 4-1, the numbers and kinds of barriers, experience, comparability to similar situations, and in some cases analytical methods. The process ends by showing the residual risk.

The column "Design Standards" in Table 4-1 lists standards for construction of hazard barriers, where available. These Standards provide a standard for equipment construction considered generally acceptable, such as the pressure vessel mechanical code. The column "Performance Standards" in the table lists standards for operation of a protection system which if followed establishes a performance level generally accepted, such as pressure vessel inspection standards. LANL Standards (AR, DP, ESH, LM, LP, LS, TB) can be found through the LANL Web pages.[i]. The tabulated standards are part of a much larger set of orders, rules, standards, etc, that apply as listed in the LANL M&O contract. Site-specific policies can be found through the LANSCE Web pages.[ii]

The results of barrier failure were assessed; typically, there are escalating consequences as more layers of mitigating factors fail, so some hazards have a range of consequence, from minor at high probability to severe at low probability. Consequence and probability of barrier failure can be ranked on the scale provided in AL5481.1B[iii] as shown in Table 4-2.

Table 4-1. LANSCE hazard inventory and controls.

Hazard	Ch.4	Controls, barriers, & mitigators	Design Standard	Performance Standard
Ionizing Radiation				10 CFR 834,835; DOE 5480.25,LM107
Prompt radiation inside exclusion areas outside exclusion areas	.2 .2.2	posting, shielding access controls electronic systems, access control	LS107-02 LS107-01, ANSI N43.1 TA53 PRPP	LS107-11 5480.25 Guidance I.F 10CFR835.501-502
Activated material access	.2.5	posting, monitoring, access control, remote handling	LS107-02	AR3-4, ESH-1-06-01, ESH-1-07-01
Activated material release	.2.6	confinement, monitoring, PPE, limited occupancy		Std 1027, LP-107-04, LS107-09, ESH-1-02-05, AR10-2, TB303, DP117
Airborne activation	.2.7	confinement , access control		onsite 10CFR835.403, offsite 10 CFR834
Waterborne activation	.2.8	confinement, monitoring		EPA 40CFR60,61; 10CFR834
Ordinary Industrial & Laboratory Hazards			29 CFR (OSHA)	
Electromagnetic Energy electrical power rf power lasers magnetic fields	.3 .3.1 .3.2 .3.3 .3.4	 confinement,posting, locks, interlocks, PPE confinement, posting, interlocks posting, confinement, interlocks, PPE posting, confinement	 NEC Industry practice	 AR7-1, TB701, LP106-01.2 LP106-01.2, AR5-1, TB502,ANSI/IEEE C95.1 AR5-2, TB501, ANSI Z136.1 AR5-3
Hazardous materials cryogens hazardous gases other chemicals explosives	.4 .4.2 .4.2 .4.3 .4.3	containment, training, PPE and ventilation	 LS106-05	LS107-06, LS106-03, AR6-1, TB6, AR 1-9 LS106-05 AR6-9 AR6-1 AR6-6, TB602
Industrial cranes forklifts workspace confined spaces & ODH pressure & vacuum sys.	.5 .5.1 .5.2 .5.3 .5.4 .5.5	training, procedures, inspection training, procedures, inspection training, procedures, inspection inspection posting, alarms, PPE vessel construction & inspection	OSHA “ “ “ “ ASME (press. vessels)	OSHA AR13-2 AR13-1 OSHA AR8-1, TB8 AR14-1
Fire	.6	building structure & contents; training; emergency response	AR11-1, AR 11-2, AR6-5, NFPA 10,13 24,101, DOE 6430.1A, 5480.7A. See Table 3-2	
Natural Phenomena	.7	building location & structure	UBC, ANSI A58.1, NFPA 78, DOE 5480.28, DOE Std 1021. See Table 3-2	

Table 4-2. Hazard categories and risk per AL5481.1B.

HAZARD SEVERITY–may cause...	PROBABILITY (PER YEAR)			
	A Likely $> 10^{-2}$	B Unlikely 10^{-2}–10^{-4}	C Extremely Unlikely 10^{-4}–10^{-6}	D Incred-ible $< 10^{-6}$
I—Catastrophic deaths, or loss of the facility/operation, or severe impact on the environment.	Un-acceptable	Un-acceptable	Marginally Acceptable	Acceptable
II—Critical severe injury or death to a worker, or severe occupational illness, or major damage to a facility/operation, or major impact on the environment.	Un-acceptable	Marginally Acceptable	Acceptable	Acceptable
III—Marginal minor injury, or minor occupational illness, or minor impact on the environment, or moderate damage/impact to a facility/operation.	Marginally Acceptable	Acceptable	Acceptable	Acceptable
IV—Negligible no significant injury, occupational illness, or significant impact on the environment.	Acceptable	Acceptable	Acceptable	Acceptable

Application of this risk scale to LANSCE is shown in Table 4-3. A darkened cell in the table indicates that this level of hazard is judged to be adequately controlled by the corresponding kind of barrier. The remaining white area is the recognized residual risk of facility operation.

Table 4-3. Application of Qualitative Hazard Categories and Risk to LANSCE.

HAZARD SEVERITY–may cause...	KINDS OF BARRIERS			
	Single systems, human reaction	Multiple systems	Systems & fixed barriers	No capa-bility
I—Catastrophic offsite death or severe injury, or severe environmental damage; loss of the facility/operation				
II—Critical onsite death or severe injury, or moderate enviro. damage; extended operational outage				
III—Marginal Onsite minor injury/illness, minor enviro. damage; brief operational outage				

4.2 IONIZING RADIATION

Radiation produced directly by the beam—prompt radiation—is a hazard when and only when the accerator beam is on. Standards, practices, and procedures for beam operation are found in the LANSCE Operations Manual (OpMan) maintained by the Accelerator Operating Group. The OpMan is effectively a two-thousand-page SOP for accelerator operation and beam delivery. Induced activity in materials following beam operation is a second kind of radiation hazard. Finally, radioactive materials can be brought and used on site. Hazards of these three kinds are discussed in this section.

4.2.1 Radiological Areas

LANSCE has a large number of radiation areas or potential radiation areas of various levels including Very High. These areas receive radiological classification and posting according to LS107-02 based on maximum radiation levels expected during normal operation.

4.2.2 High Radiation Area Access Controls

The facility handles access to radiological areas in various ways depending upon the radiation level and whether the radiation is present under normal operation or only under abnormal conditions, whether access during beam operation is allowed or not, and whether the radiation is due to beam operation or radioactive material. High and Very High Radiation areas are provided access controls as shown in Table 4-4.

Table 4-4. Access Controls for (Very) High Radiation hazards.

Hazard:	**Prompt Radiation (Accelerator beam on)**		**Radioactive Material**
Condition	Normal operation	Abnormal operation	Beam Off
Rad. level	(Very) High	>1 rem/h, (Very) High	>1 rem/h, (Very) High
Standard	LS107-01, DOE 5480.25	PRPP,10CFR835.502	10CFR835.502
Access Allowed	1) Personnel Access Control System (PACS/PSS/IPSS)	3) Special Access Control Area	5) Walls, fences, locked gates; enter with RCT or RWP
Access Normally Not Allowed	2) Locked and possibly interlocked	4) Locked and possibly interlocked	6) Walls, fences, locked gates

Cell 1 in the table applies to the usual beam delivery area and is the usual case—for the ideal accelerator, it would be the only radiological area. During normal operation while beam is on, the area is a (Very) High Radiation Area, and access is prevented by the PACS (or PSS or IPSS); during occupancy, beam delivery to the area is prevented and the radiation is low.

A few secondary beams deliver less than 1 rem/h or even 0.1 rem/h. Federal regulation 10CFR835.502 requires positive access controls above 1 rem/h. Since there is no compelling reason for beam-on occupancy, typical accelerator practices and standards such as LS107-01 require locked or interlocked barriers for beam delivery areas above 0.1 rem/h, the High Radiation Area defining level.

If entry is unnecessary during normal operation (cell 2), access is usually prevented with a lock; these areas are usually also equipped with interlocks to automatically prevent beam delivery if the access gate is open. Adminstrative control can also be used. If the area could be a high radiation area under abnormal operation but access is not needed, it is treated the same way, as shown in cell 4. If access is needed to an area possibly at risk from abnormal operation, it is handled under special limited access rules (cell 3).

Access to areas with high radiation due to radioactive materials is controlled by locked barriers; if entry is allowed (cell 5), it is made with a Radiation Work Permit or accompanied by a Radiation Control Technician. The same area can have any combination of hazards from the three columns—for example, a beam delivery area can also have Highly radioactive materials present. In such a case, the PACS is normally also used as the access lock, for example with RCT control of the entry keys. (Similar procedures can be used to control access to areas with other combinations of hazards such as prompt radiation and lasers.)

4.2.2.1 Personnel Access Control System

Access controls for areas with high radiation from beam operation have a consensus standard reflected in DOE Order 5480.25 Guidance Section I.F, ANSI N43.1, and Laboratory Standard LS107-01. These standards relect stricter requirements than found in 10 CFR 835, including redundancy. The Access Control chart from LS107-01 is attached as Appendix 4-1 to this SAD (see the Standard for full explanation). In 1996, a few beam channels at LANSCE meet the requirements of 835.502 but do not meet the interlock redundancy standard. Upgrades are planned.

At LANSCE, all primary beam delivery areas are totally enclosed by shielding, with gate access. All secondary beam delivery areas are enclosed by shielding or fences, with gate access. These areas all have *Personnel Access Control Systems*, which interlock gateway access with local beam-off mechanisms. When beam is on to a PACS area, it is an *exclusion area*—occupancy is excluded. There are about one hundred PACS areas, and typically a few change each year. The operating/area support groups maintain descriptions of the areas under their control. Configuration control is maintained by the operating groups and monitored by annual readiness reviews conducted by the TA53 Radiation Safety Committee. The hazards, barriers, and risks are typical for accelerator facilities.

PACS is the upgraded version of the earlier Personnel Safety System (PSS) or Instrument Personnel Safety System (IPSS). References to PSS and IPSS will be found in some LAMPF-LANSCE documentation.

The difference between PACS (Table 4-6 cell 1) and the lock/interlock combination in cells 2–4 is that PACS prevents opening the access gate when the area is not safe, whereas separate gate-open interlocks create a fault condition when the door is opened. Interlock standards do not permit the latter for routine access (in the ideal facility, actuation of the safety system by a fault condition would never occur).

To assess radiation conditions after beam is turned off, procedures require the first entry into any primary beam area (above 1 MeV) following beam delivery to be made by a Radiation Control Technician (RCT) operating a radiation detector. Once a determination has been made of the radiation level, appropriate positive access controls are set up but during maintenance operations this can sometimes take the form of surveillance and monitoring rather than fixed barriers. These measures are considered to be equivalent to other positive access controls, and this hazard is typical for accelerator facilities.

4.2.3 Shielding

An overview of the “permanent” shielding was given in Section 3.3.1.1, *Shielding Design and Layout.* One useful measure of shielding effectiveness is the radiation level that a point radiation source of known strength in a beam tunnel causes in nearby occupiable areas. The relation of radiation levels in occupiable areas to beam power is a function of shielding “thickness,” including material composition, and distance.

The effective shielding thickness together with the loss of primary beam power along the beamline tolerated during normal operation give the expected prompt radiation dose rate to personnel. Likewise, the thickness together with the maximum beam power that can be lost anywhere along the beamline in a credible circumstance give a measure of hazard which can be profiled throughout the facility. The probability of the radiation-generating event and the effect of mitigating elements such as radiation detectors then describes the risk. The dosimetry program is a means of monitoring the effectiveness of the system.

Where the shielding is thick and the geometry is simple, calculation is adequate to characterize the shielding effectiveness, perhaps with spot checks. Where there is some question about the adequacy of the model, extensive measurements have been made. However, during normal operation most occupiable areas have very little prompt radiation, and whatever is measured often cannot be associated with a particular source. In order to assess shielding effectiveness directly, point-source testing must be performed.

Extensive measurements have been conducted throughout the facility—in all, hundreds of points have been checked in more than a dozen separate experiments. In these tests, a low beam current—just sufficient to produce a stable and measurable level on gamma and neutron detectors, usually in the range 10–100 millirem—was targeted, usually on an available or inserted obstacle, and radiation levels were recorded in outside areas.

Beam spill experiments are fairly difficult and substantial uncertainties surround the extrapolated rates. First, for safety and ALARA reasons, the tests are done at the low beam current and the measured radiation levels are near the low end of the instrument range. Second, the targeted item does not necessarily produce the same radiation as would occur in an actual accident and is not likely to be in exactly the same place. Third, no instrument is capable of direct reading of rem over a wide range of neutron energies; in most of these tests, a spectrum estimate was made by a set of Bonner Sphere measurements for spectrum correction (or/and in some cases by a Monte Carlo simulation calculation), introducing another possible source of error. Estimates may be good to a factor of two or three. The highest levels measured or calculated for each area are tabulated in Table 4-5 for the "Design Basis Accident."

In the Instrument column, A indicates use of the Albatross neutron direct-reading dosimeter, and B indicates the use of the set of Bonner Sphere measurements or the foil-activation method. Method B was used to estimate the higher energy portion of the neutron spectrum, > 20 MeV, which can be under-read by the Albatross. If the radiation levels were low, the spectrum correction does not influence the conclusions and therefore was not done (spectrum factor of 1); also, relatively low levels indicate a low component of energetic neutrons and consequently a smaller correction factor.

Table 4-5. Maximum radiation outside beam delivery areas in design basis accident.

Source Location	Test Beam (nA)	Target	Dose Location	Meas. (mrem/h)	Instr §	Spectr. factor†	Max.[b] dose rate rem/h	Reference
1 mA in the Linac and Switchyard								
TR	3400	TREM1 (~3/4" Cu)	Service aisle		A	1	0.6	AAB memo 6/29/93
Sec B			Top of shield door			1	60	Linac Review 5/96
Sec F-G-H			Bottom of stairwells				50	
Sec H	2800	3/4" Cu block	Service aisle	1.1/µA		1	1.6	AAB memo 6/29/93
SY	10µA	SYBS	Cable duct	35	A		3.4	MVH memo 7/4/91
LDBM12-13	315–3500*	Cu z=15cm, d=10cm	LDN berm[e]	160 1532	A&B	x2 self shield, x3 spectr.	52000	PSR90-005 PSR 91-013
150 µA in Line D to MLNSC								
LD-road	500*		road surface	10*	A&B		15	PSR91-013
1LSM		4x4x8" Fe, R.Nelson calc	ER1[a]	N/A	N/A		150	RSC 5/31/95
PSR			REB				150	MLNSC Review 6/96
150 µA in Line D to WNR (1R beamline)								
1R		R.Nelson calc	ER1				350	RSC 4/9/96
1R	na	R.Hutson calc	ER2	na	na	na	176	RJM memo
1R	na	R.Hutson calc	MEB roof	na	na	na	145	M. Plum memo
1 mA in Line A								
Area A, top of shielding	na	Calc.	na	na	na	na	62	
10 µA in LineX-B-C								
LB	110	EP-BL-0	EB1	15	A	1	1.0	RSC 6/25/91
Area C	~300	Fe 6x6x12"	dome top[e]	~10	A	1	0.3	

*"Normalized" values; actual current and mrem not quoted in report.
§ Instruments: A = Albatross (used for rem), B = Bonner Sphere (used for spectrum correction).
†Factors used to multiply measured or calculated dose to correct for spectrum and geometry.
[e]Exclusion area. LD North berm is above Line D ramp leaving Switchyard, enclosed by fence.
[a] Limited access area.
[b] Without radiation instrumentation; RSS instrumentation generally limits dose to <1 rem/h

4.2.3.1 Shielding Policy[•]

The LANSCE Prompt Radiation Protection Standard requires for:

7.1. Protection During Normal Operation. The shielding and access control perimeter shall be configured to support ALARA objectives. Access controls and area postings shall be made to comply with LANL standards. Detailed interpretation of the access control requirements and oversight of implementation shall be made the responsibility of a special committee.

7.2. Protection from the Design Basis Accident. The shielding shall be configured so that no offsite exposure to a person can exceed 1 rem. Onsite areas which have a potential radiation dose rate exceeding 25 rem per hour in the design basis accident shall have special access controls based upon evaluation and acceptance of the risk by the operating organizations.

The LANSCE Prompt Radiation Protection Policy (PRPP) gives the following definition: “The Design Basis Accident is an extreme condition assumed for purposes of defining the hazard level. By default, it is assumed to start with delivery for up to one hour of the highest beam power that can reach an area with any combination of credible failures of the beam distribution system, and beam impingement where it would produce the highest radiation at any place accessible to a person outside secured areas. The radiation safety analysis of each primary beam area should consider factors limiting beam power, accident duration, and radiation, and develop the design basis accident scenario in detail.”

The LANSCE Radiation Safety Committee (Minutes, 9 April 1996) and the Facility Landlord (response, 11 April) determined that the beam current entering into the Design Basis Accident (DBA) for determining *on-site hazard* should be equal to the setpoint in the Beam Current Limiter (XL) system in each beamline.

Presently the linac and Line A do not have an XL system. The full possible current in the linac cannot be known precisely but is not thought to exceed the normal maximum production current (<1100 μA, sum of both beams) by more than a small factor, probably less than 2. This factor would not substantially change the hazard in occupied areas.

The effect of the PRPP and the current limiter policy is to require:

- shielding thick enough for ALARA purposes under normal operation,
- shielding thick enough to limit nearby dose rates to less than 25 rem/h for impingement of the set-point limited current, otherwise treat the area with special (limited) access controls, and
- shielding thick enough to limit offsit dose rates to less than 1 rem/h/mA.

4.2.3.2 Reliability of Beam Safety System

In 1990, a team of six analysts from LANL Group N-6, the Engineering and Safety Analysis Group in the Nuclear Technology and Engineering Division, and five contributors from MP Division (AOT Division predecessor) performed a limited-scope probabilistic risk assessment (PRA) for the Line D beam safety system operation. This study (Sharirli 1990) concentrated on the RSS, and particularly the beam plugs, associated interlocks and controls, and the beam current limiters (XLs). The results of this study are included in Table 4-6.

Table 4-6. Failure factors to reach 25 rem in Special Access Control areas.

	(1) Beam mis-steered to weak spot	(2) Beam distri-bution, timing, gating, or chop-ping failure	(3) Fast Protect inter-lock system failure	(4) Run Permit inter-lock failure—includes radia-tion detec-tors	(5) RSS double failure—includes Current Limiters	(6) Beam stays on & area occu-pied for (min-utes)	(7) Occu-pancy factor #	(8) Access by
Est. error rate/y or unavailability	0.1	0.02	0.01	0.01	0.004	0.1-0.001		
Line D road crossing	X		X	X	XX	100	L	open
1L/ER1	X		X	X	XX	4	M	badge
1R/ER1	X	X	X	X	X		M	badge
REB	X		X	X		1.5	L	badge
MPF-7 MEB	X	X	X	X	XX	10	L	badge
1L Compressor Area	X	X	X	X	XX		L	badge
Area A shld'g fence	X		X		[RCT does not notice]	25	L	key
EB Room	X	X	X	X	XX	20	L	key
BR neutron area	perm. mag fails		X	X	XX	*	M	badge
Sec B truck access	X		X			20	L	key

*shielding and controls presently under design; operation not planned in 1996.
L = Low occupancy; M = Moderate occupancy (occupied 3-30% of the time)

System analysis included RSS and XL success criteria, scheduled testing and surveillance, human reliability analysis, common cause failure analysis, fault tree development, modeling assumptions and definitions, combinations of failure-causing events, and fault tree analysis. The unreliability of systems was calculated: that is, the failure probability of the XL and RSS to detect, respond, and operate as required in an accident scenario.

The PRA analysis provided tens of thousands of combinations of events that could cause RSS failure, leading to an XL system unreliability of 9×10^{-4}. The results were dominated by three single causes resulting from potential human errors during weekly and pre-operation tests. The XL-RSS failure paths were dominated by five common-cause failure events and one contributor due to human error during preoperational tests yielding a failure probability of 4×10^{-3}. The RSS since has been, and continues to be, upgraded to improve its capabilities and meet high quality standards.

4.2.3.3 Special and Limited Access Control Areas.

The Special Access Control Area (SAC) designation applies to areas that can have high radiation levels during abnormal operation but where personnel passage or occupancy is conditionally allowed (cell 3 in Table 4-4). An SAC Area results when access is needed to an area but the shielding between it and an adjacent primary beam line is marginal against the design-basis accident scenario. These cases are handled individually according to the LANSCE Prompt Radiation Protection Standard and the Limited Access Control policy. Management reviews the risk and determines the special access controls to be used, which can be no restrictions at all, sign warnings, badge-controlled entry, Radiation Work Permit entry, and other appropriate conditions. This level of access control is allowed by 10 CFR 835.502 and LS107-01 and is considered to have very low risk due to the infrequent presence of the hazard (available records indicate no occurrences).

Limited Access Control (LAC) areas are a subclass of Special Access Control Areas which meet more specific criteria (Appendix 4-2) including an access control system, instrumentation, and location-specific training.

SAC areas planned for operation in 1996-97 are shown in Figure 4-2. Several cases are described below.

The top of the bulk shielding in Area A is estimated to have a radiation level up to ~60 rem/h in the design basis accident. It is a fenced area with locked gates during beam operation. Entry is permitted under certain conditions (in 1995, when accompanied by an RCT operating a radiation detector). The area is rarely occupied and several concurrent failures would have to occur for significant personnel exposure to result.

La Mesita Road crossing over the Line D tunnel (Figure 4-2) is estimated to have ~15 rem/h dose rate for the design-basis accident. The on-site design basis accident assumes the beam-limiting controls operate properly. Personnel dose accumulation of 15 rem would require many concurrent failure conditions. TA-53 management concluded that no access restrictions, or at most warning signs, were adequate controls for this area.

The MLNSC Experimental Room 1 (ER1), is operated as an LAC Area in 1996. Two beam lines run through shielding overhead and present a design-basis accident hazard up to 350 rem/h. Personnel dose accumulation of several hundred rem or more would require many concurrent failure conditions including occupancy of the localized hot spots concentrated near the room ceiling and is considered extremely unlikely or incredible. However, in view of the magnitude of the hazard, entry is restricted to badged individuals given special training on risk awareness. This risk is considered commensurate with the risk of normal entry into PACS areas, where multiple failures could also lead to high dose rates, and is therefore considered in line with normal accelerator practice.

Figure 4-2 shows several kinds of Special Access Control areas. ER1, the Area A shielding enclosure, and La Mesita road crossing were discussed above. Other examples shown include the EB lower level—marginally below the radiation hazard for SAC

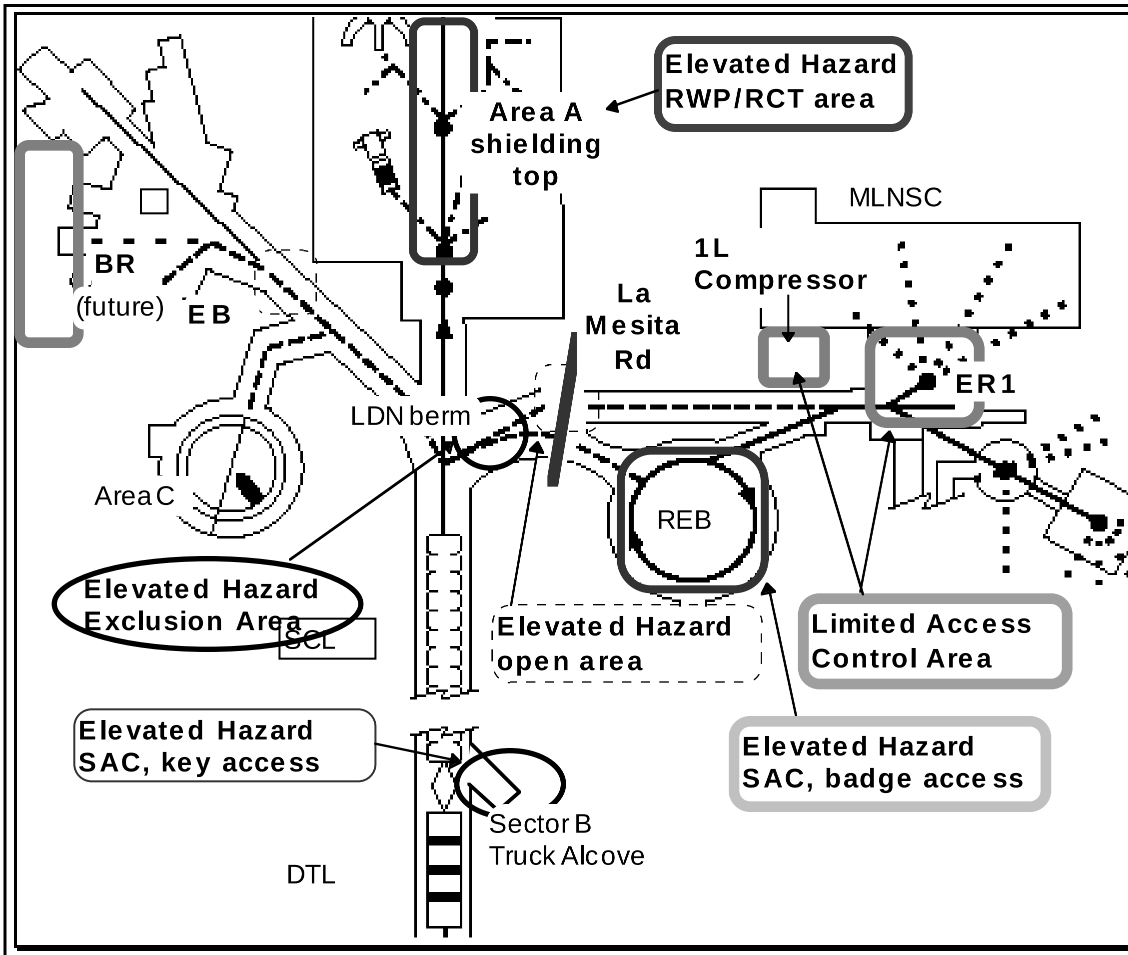

Figure 4-2. Special Access Control areas.

consideration, and the Line D North berm and the Sector B truck alcove—both exclusion areas because beam-on access is not needed.

The factors which would have to fully overlap to create an accident with consequences exceeding 25 rem to a person are summarized in Table 4-6. Column 1 indicates that safe occupancy might be challenged about once per decade by high-power beam impinging on the particular vulnerable area. The failure rate or unavailability of the different layers of the control system to respond adequately is indicated in the second row of the table in columns 2-5 and is based on extensive experience and some analysis. Unavailability is the fraction of time the subsystem would not respond adequately to a challenge. Failure rate is the fraction of challenges the subsystem fails to meet. Column 3 indicates that the Fast Protect system, the first layer of mitigation, might be expected to not respond 1% of the time, and so forth for Run Permit and RSS. The probability of the joint occurrence of more than one factor cannot be taken to be the product of individual failure probabilities because of the possibility of common-cause failures. Some of the factors, such as missteering a high intensity beam to a special spot, leaving it there, and not ending in self-destruction, are highly unlikely in themselves. If all barrier failures overlap, the situation including occupancy must endure for the time in column 6 to accumulate a 25 rem dose. These times are all sufficient for personnel to respond to audible and visible alarms as the last line of defense.

4.2.3.4 Prompt Radiation at the Site Boundary

The LANSCE Prompt Radiation Protection Standard requires that “The shielding shall be configured so that no offsite exposure to a person can exceed 1 rem.” Because the nearest site boundaries are several hundred meters from the closest beam delivery areas and heavy shielding covers primary beam areas, prompt radiation at the site boundary would be negligible under the worst case of full current beam impingement anywhere in the primary beamlines and is immeasurably low under normal operation.

4.2.4 Incidental Radiation

X-rays are can be created by energetic electrons in vacuum striking surfaces. Thus high-vacuum rf and hv devices can produce x-rays; such devices are present at LANSCE and the production of x-rays from them can be a byproduct of normal operation. The principal incidental sources are listed in Table 4-7.

X-ray device safety, including incidental sources, is addressed by LS107-03. Potential sources of x-rays, readily identified by the characteristics in the preceding paragraph, are monitored by radiation control technicians (RCTs) and appropriate controls, including shielding, posting, warning barriers, and access controls, are instituted. Handling of each device is covered by an SOP.

The DTL in Sector A can produce High Radiation level x-rays. Access controls are used to interlock Sector A access with DTL rf power. The 80 kV beam in the H^- injector dome can produce a Hot Spot. This hazard is controlled by posting, shielding, audible and visual alarms, and low occupancy. Other incidental x-ray sources are controlled as shown in the table.

Table 4-7. Incidental x-ray sources

Device	Area Classification	Control
DTL–Sector A	High Radiation Area	PSS interlocks
H^- 80 kV column	Radiation Area & Hot Spot	Shielded & posted
H^+ & H^- inj. 750 keV columns	Controlled Area	Posted; audible alarms
H^- beam modulator/deflector TB-BD	Hot spot	Posted & panel interlocks
ETL & Sector B-H klystrons	Controlled Area	Shielded & posted
Area A (SMC) beam separator	Radiation Area	Shielded & posted
Area A (SMC) beam chopper	Radiation Area	Shielded & posted

Because of the generally low energy and low intensity in LANSCE incidental x-ray fields, and the ready identification of possible sources, the risk is low from this hazard.

4.2.5 Radioactive Materials

Radioactive materials all present the hazard of ionizing radiation. Barriers used usually include confinement and sometimes access controls. The implementation depends upon the nature of the material. The following discussion deals with materials intentionally activated by the beam including isotope production and materials studies, collaterally activated solids and airborne and waterborne activation products; and radioactive materials brought to the facility.

4.2.5.1 Radioisotopes made during operation

To inventory quantities of isotopes made on site, a systematic screening process was employed by considering all materials directly exposed to the primary beam. First, radioisotope inventories were calculated for targets and beamstops intercepting the high-power beam, as shown in Table 4-8.

These results indicated that radioisotope inventories for ordinary accelerator component materials did not need to be considered if the components did not have lengthy exposure to at least 10 kW of beam power. Therefore further evaluation was excluded of structures such as tuneup beamstops and the copper in the accelerator intercepting low levels of beam.

Because of their proximity and obvious common-mode failure mechanisms, the three A6 components (A6BS, IP, and APT [REF inserts]) will be considered together. Table 4-8 shows that A6 beamstop and the 1L Target (Figure 3) each have ~10^2 TQ3 (Category 3 Threshold Quantity) inventory as an order of magnitude, and other areas are negligible or have only transient inventories. Not included in this quantity is another 10^2 TQ3 of material activated in the bulk shielding, because this activation is dilute and lacks exposure to an energy source to drive dispersion. A6 and the 1L Target are isolated from each other physically and therefore are considered separately. Appendix 4-3 gives a detailed inventory of the calculated radioisotope inventory.

Limited life facilities. Several of the modules, as denoted in the table, are not foreseen in operation past 1998.

Table 4-8. Radioisotopes made during operation.

Target or beam stop	material	size or quan-tity	mA-m-y	Isotope inventory	comment
			A6 Beamstop area		
A6BS	Cu	20cm D x 70cm L	1x5x5	~0.5 TQ3 in Cu BS and SS front face	In shielding vault. LLF*; end 1997
IP	variety		~1	~30 TQ3	In shielding vault. LLF; end 1997
APT	SS & W.		8	10^2 TQ3*	In shielding vault. LLF; end 1997
			MLNSC Target		
1L Target	W,Cu,Ni,..		0.1x5x5	50xTQ3 in W target and Ni reflector	In shielding vault.
			WNR targets		
1R Tgt 2	variety		0.003x1x1	Low exposure	not considered further
1R Tgt 4	W		0.003x5x5	Low exposure, < 1 TQ3	In shielding vault.
			Other		
A1 target	C	L=2cm	12	Low activation	TQ3 < 1
A2 target	C	L=4cm	12	Low activation	TQ3 < 1
RI-BS					(PSR inj. beamstop)
Bulk shields	iron & other		indirect	~10^2TQ3	dilute; no direct energy source
LC,LB-BS	iron		0.01	Very low exposure & low activation	not calculated. Limited future use.
Notes				*final design & evaluation in process	***LLF**=limited life facility

4.2.5.1.1 Material at Risk.

When an Isotope Production target is inserted and the beam is on, the energy source (beam heating) to initiate dispersion via vaporization is present. When the target is retracted, there is no evident energy source to drive dispersion until the target is being transported or processed. Irradiated targets are removed from the isotope production stringers and loaded into the transfer cask prior to shipment to the processing facility. This operation is carried out following an SOP inside the IP facility using remote handling equipment. This analysis covers only the isotope production process at the LANSCE A6 facility, not the subsequent steps, which are covered under other documentation.

All targets and materials when subject to melting or vaporization by the beam are enclosed in shielding vaults. The shielding vaults have no occupiable space within them and are not accessible while beam is on. The shielding vaults are very heavy, with meters of thickness of steel. Figure 4-3 shows the A6 vault and Figure 3-19 shows the 1L Target vault.

Given that above-TQ3 isotope inventories are present, credibility of dispersability via the air pathway of significant quantities to occupied areas can be addressed.

Inhalation of airborne radioactive material released from beamline components could proceed through the following sequence of events:

Failure of beam interlocks to protect against loss of cooling water and overtemperatures
Melting of significant quantity of activated material
Evaporation/vaporization of significant quantity of activated material
Vapor or aerosol reaching occupied area
Presence of personnel in endangered area
Failure of radiation interlocks to terminate beam delivery or warn personnel to leave.

The scenario has two branches depending on whether the air exhaust system is in operation. If the area exhaust system is On (normal condition), airborne activity will be largely taken up, largely filtered out, and released from the air stack in greatly diluted form. If the exhaust system is Off (interlocks failed), then airborne activity can diffuse into the building. At A6, the A-East building is overhead and can be occupied. At MLNSC, the nearest occupiable space is ER1–to the side; the 1L Service building overhead is an exclusion area when beam is on.

The highest hazard at the **A6 facility** appears to reside in the APT assembly, where the isotope inventory will be about 100 x TQ3 after irradiation. In a loss-of-cooling situation with failed interlocks, a substantial portion of the targets could melt. When the material reached its melting point, it would flow down out of the beam path, drip onto the cold steel shielding, and resolidify. The metallic vapor release would be a microscopic fraction of the material mass, and much of the metal vapor would plate out. An upper limit to the fraction diffusing to occupiable areas might be crudely estimated by the fractional area of open cracks in the shielding, which must be kept under 1/1000 for considerations of neutron ducting and escape of activated gases. Our conclusion is that the MAR << 1 TQ3 in the A6 beamstop area.

For the **1L target**, it is likely that the tungsten target would never melt. If it melted, it would release very little vapor. Movement of this vapor into occupiable areas in ER1 would be inhibited by the target system vacuum windows, beam shutters and windows, and shielding enclosures. Release of 1 TQ3 to occupiable areas is not credible.

4.2.5.1.2 Interpretation of Standard 1027

In DOE Standard 1027 Attachment 1, the background for the Threshold Quantity 3 calculation indicates that the context is for "protection of workers for planned reentry into a facility after an incident....the models used assume that persons are exposed for one day...". Since the assumed scenario would not appear to apply to accelerator facility operations—there being no compelling reason for less than fully protected reentry—an interpretation of the Guidance in line with the principles of graded application and reasoned approach would be to assume a 1-hour exposure, consistent with the 1-hour design basis accident referred to in the Standard for Prompt Radiation Protection at TA-53 (Attachment 2), and in the (withdrawn) Part I.A of the Guidance to Order 5480.25. This time element would scale down release fractions by a factor of 24. If applied to the 1L target, the target system radionuclide inventory would barely exceed 1 TQ3.

Material stored on site. Irradiated materials with high specific activation are sent to LANL radioactive disposal facilities. Components with low specific activation and of possible future utility can be kept on-site in storage yards. Appropriate physical controls are maintained per 10 CFR 835. The radioisotope inventory in these components has not been determined in detail. However, based on the rule-of-thumb given above as well as low residual activation, no stored components have received sufficient irradiation to contain TQ3-levels of isotopes.

Radioactive materials brought on site. Radioactive materials are brought on site for short-term (transient) use in research, sometimes with TQ3 > 1 (see next section). Each experiment has individual safety review per AOT-FM policy 53FMP 114-01.01 and appropriate safety management. Controls and barriers are implemented according to the nature of the material and the hazards.

Based on the above considerations, LANSCE is a Candidate Nuclear Facility but a Non-Nuclear Facility Categorization for the base operation is proposed because of the small fractions releasable to occupiable areas from materials activated by the beam.

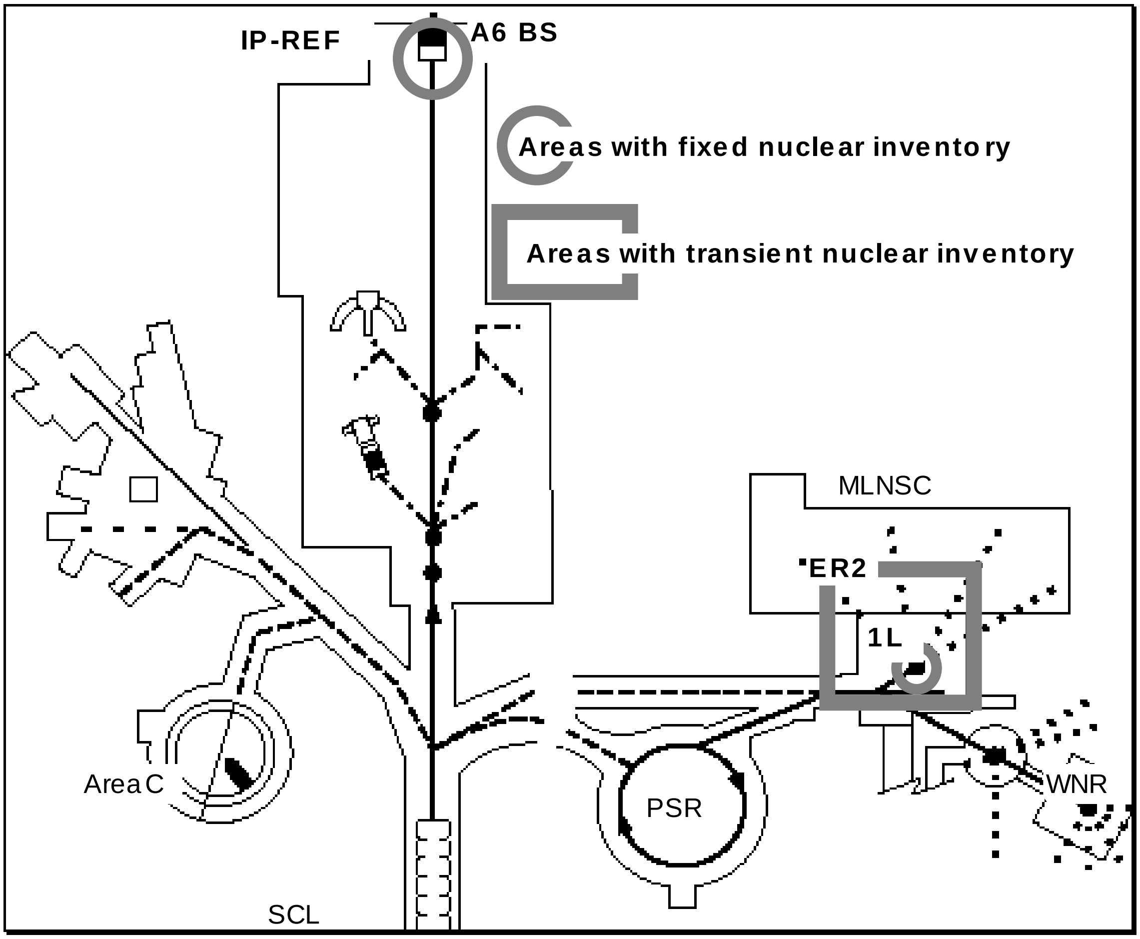

Figure 4-3. Areas with significant nuclear inventories.

The areas with significant nuclear inventories are shown in Figure 4-3.

4.2.5.2 Radioisotopes Used in Research

Radioiostopes are brought onsite for use in research. The quantities may sometimes exceed TQ3. Multiple barrier layers are used to manage this risk. Depending upon the isotope,

quantity, and material form—solid, liquid, gas, powder, etc.—the controls used can be physical containment, an SOP, special training, PPE, workspace and personnel

monitoring, air control, and other appropriate measures, as given in LM107-01 (the Laboratory Radiological Control Manual) Chapter 3 (Conduct of Radiological Work) and Chapter 4 (Radioactive Materials).

The following control requirements apply to actinide use: (1) powdered thorium or uranium samples are allowed in sealed metal containers; (2) solid metallic samples are packaged to avoid surface contamination during handling, and (3) powdered actinide samples are doubly encapsulated in sealed metallic containers with wall thickness at least 0.25 mm, and checked for integrity by radiographic or vacuum leak-checking. Exceptions to this requirement, such as bare samples or glass containers, are handled under Special Work Permits.

An RCT tests for surface contamination on every sample each time one is removed from storage or replaced in storage, and checks its radiation level after it has been irradiated. The RCT may also specify additional precautions such as surgical gloves, anti-C clothing, or respirators depending on their estimate of the risk of contamination, when they review the Special Work Permit.

Powdered actinide samples are normally installed mounted in a vacuum chamber during the experiments. The vacuum pump is exhausted through a HEPA filter. A continuous air monitor (CAM) is placed in operation by the RCT at the vacuum exhaust or near the sample for all powder or liquid actinide samples. The CAM alarm is connected to the Central Control Room (CCR), and the CAM is backed up by a 20 minute non-interruptable power supply. An RCT checks the CAM once per shift and changes the filter paper once daily throughout the duration of the experiment.

Detailed checklists are provided for response to a CAM Alarm, a Breach of Sample Containment, Failure of Continuous Air Monitors, a Fire Alarm and Evacuation while an Actinide Sample is on Site, and for critical systems checkout prior to, and during the experiment.

All planned operations on activated equipment require review through the Radiation Work Permit process. Control measures routinely used include training and planning, radiation surveys, surface swipes, use of personnel protective equipment, special floor coverings, special access controls, air monitoring, portal monitoring, trash monitoring, and site exit gate continuous automatic monitoring (Section 3.3.2.4). These measures are very thorough and have demonstrated the capability to identify very small amounts of activated materials.

Limitations on isotope quantities for operation within this SAD are discussed in the Safety Envelope, Chapter 4.

4.2.5.3 Radioactive Calibration Sources

TA-53 groups holding calibration sources maintain inventories. The Laboratory’s requirements for handling radioactive sources and samples are given in LM 107-01.1, “LANL Radiological Control Manual” (LANL LM 107-01.1), and “Radiological Source Control” (LANL AR 3-4). Items on hand may vary according to the immediate need, but detailed procedures for receipt, handling, storage, and disposal are published in SOPs for the quantities and hazard levels normally permitted on site. Items beyond normal limitations must be fully described in a Special Work Permit requiring supervisory approval and ESH-1 review.

4.2.5.4 Radioactive Parts, Fragments, and Contamination

Spread of activated material in the form of small parts and fragments presents a pervasive hazard with correspondingly many approaches for control, as described earlier in Sections 3.3.2.1–4. This hazard tends to be concentrated in the high-power target and beamstop areas, including the A6 beamstop facility including ISORAD. The environment near the A6 beam stop produces considerable corrosion on the target carriers and stringer ends. Some of this corrosion finds its way into the ISORAD pit as radioactive contamination. Similar conditions apply to the Area A and MLNSC target cells when a target or component is changed. Much lower levels of activation can be found in many parts removed from any of the main beam lines for maintenance, and the whole main beamline vacuum envelope from the DTL onwards is posted and treated as a Radiological Materials Management Area.

It is relatively straightforward to identify areas containing this hazard, anticipate its magnitude, and apply appropriate control measures per LM107 Chapters 3 and 4. Barriers routinely used include work planning, pre-work radiological surveying, workspace monitoring, PPE, work area exit monitoring, control of airflow, floor covering, and cleanup. Monitoring and airflow control includes when appropriate air monitoring and workspace enclosure or control of doors. Cleanup can include use of vacuum cleaners equipped with HEPA filters. The last barrier to migration of radioactive pieces and parts offsite is provided by the site exit gate monitor.

Risks from this hazard range from frequent low-consequence occurrences to an improbable high-consequence occurrence, presumably managed adequately by the LM107 procedures.

4.2.5.5 Airborne Activation Products

Airborne radioactivity can result from activation of air by normal beam operation, or release of radioactive gases, or entrainment of radioactive particulates.

4.2.5.5.1 Onsite

Areas of possibly high concentrations of airborne activity include the Line A beam channel, particularly the A6 beam stop area, the PSR tunnel, and rooms with dispersable radioactive experimental targets. Barriers used include containment, dilution, monitoring, access controls, and PPE, as determined to be appropriate for the job by the work group and ESH oversight.

The air activation in normally occupiable spaces resulting from normal beam operation has low specific activity and is adequately checked by routine rather than job-dedicated monitoring. In addition, air clearing time—typically 2 hours—and entry monitoring is used in caves and tunnels with significant air activation levels. Presently these areas include the IP cave, the REF cave, and the PSR tunnel.

4.2.5.5.2 Offsite

The monitoring of stack FE-2 and FE-3 emissions is discussed in Section 3.3.2.5.2 of this SAD. The monitoring of diffuse emissions from the various LANSCE buildings where radioactive air is present is discussed in Section 3.3.2.5.1. The equipment is operated and maintained according to extensive procedures. A short-term failure of the equipment would have no direct safety consequences except in combination with other barrier failures against excessive airborne activation and emissions.

4.2.5.6 Waterborne Activation Products

The facility is equipped with a radioactive liquid waste drain system as described in Section 3.2.8 and monitored as described in Sections 3.3.2.5 and 3.3.2.7. Spilled cooling water puddles are checked by an RCT. Vacuum cleaners dedicated for this purpose are available for cleanup if necessary. Risks from water activation are well-confined.

4.2.5.7 Transportation of Radioactive Material

Offsite transportation of activated materials from LANSCE follows LANL, DOE, and DOT regulations (LM107-01 Article 423) and is done following approved SOPs. Activity can range from barely detectable (such as on anti-contamination clothing) to thousands of rads/hr. (such as targets or beam stops). The hazards include loss of control of radioactive material and consequent possible personnel exposure and environmental damage. Many layers of barriers are invoked appropriately according to the material and activity. Barriers include use of sturdy containers with shielding, extensive monitoring, use of special vehicles, and driver training. Special containers are available for transportation of large or highly-activated components.

Isotope Production targets are transported to the LANL processing facility (outside of TA-53) under conditions of an SOP and using a 6 ton shielded cask constructed specifically for this purpose. Evaluation of this operation (Rhyne 1994) shows that the probability of a accident involving release of the cask contents is extremely unlikely, bordering on incredible. The hazard severity is marginal and the risk is low.

4.3 ELECTROMAGNETIC ENERGY

Electromagnetic energy in various forms from circuit electricity, rf power, laser beams, and static fields is virtually omnipresent at LANSCE. The hazards of various forms are discussed below in the same order, according to descending estimated risk.

4.3.1 Electric Power

Electrical power is used at LANSCE principally in installations meeting industrial standards. The hazards arising from contact of the human body with electric circuits are well known and emphasized in safety training classes required for all workers who operate or maintain electrical equipment. The hazards also include flash burns and spray of molten metal possible from short-circuits in high-power systems. Laboratory AR7-1 and TB701 provide the principle guidelines for safe electrical work.

4.3.1.1 Electric Power Systems

Journeyman electricians employed by the Laboratory's maintenance and support services contractor are responsible for maintenance and changes in the electrical distribution system including the permanent ac wiring.

LANSCE workers who are qualified by training and experience are permitted to operate and make modifications to electrical equipment connected to the distribution system. As-built drawings and maintenance procedures are available for all electrical installations and equipment.

All construction or modification of electrical equipment at LANL conforms to NFPA 70, the National Electrical Code (NEC), 29 CFR 1910 (Electrical), and DOE 5480.1B. LANSCE facilities are covered by 29 CFR 1910.302 through 29 CFR 1910.308, which includes electrical systems used in buildings, structures and premises. Worker safety and lockout/ tagout are addressed in 29 CFR 1910, Subpart S and J, respectively. The control of hazardous energy (lockout/tagout) is covered by 29 CFR 1910.147. (It is also addressed in LANL documents LP 106.01.2, and -02.1). TA-53 has a facility-specific implementation plan for lockout/tagout. Unique electrical hazards that arise from accelerator operations and experiments are covered in Special Work Permits (SWPs) and Standard Operating Procedures (SOPs).

The TA-53 Facility Management team conducts electrical safety inspections, and maintains a process to follow up with corrective actions on deficiencies. The TA-53 Electrical Safety Committee, a subcommittee of the TA-53 ES&H Council, discusses facility-specific electrical safety issues and makes recommendations to line management or the Facility Manager.

4.3.1.2 High-Power Equipment

High power equipment is characterized by high currents or high voltages or both and includes the rf and magnet power systems.

LANSCE personnel have responsibility for electric power downstream of the 4160 V manual disconnect on the rf pads, including the vacuum breaker. However, crafts workers are normally be employed for large jobs anywhere in the system.

Hazard barriers routinely used include grounding to a grounding network, interlocked enclosures, lockout/tagout on the energy source, shorting devices, and PPE such as safety glasses or face shields. Virtually all work is covered by SOPs or SWPs; these invoke the “two-man” rule if required by AR7-1/TB701 for the power levels involved.

The grounding network and good grounding practices ensure that equipment exterior conducting surfaces are at ground potential. The parts of the grounding network that are outside of buildings are checked regularly.

The rf power supply capacitor rooms present a high hazard also found in the power industry but otherwise infrequently in the workplace in the form of stored electrical energy up to 250 kJ and 90 kV. An extensive system of interlocks is provided to minimize personnel exposure to this hazard. Access to and work on the rf high voltage system is restricted to a small number of trained people and is guided by SOPs.

4.3.2 RF Power

High rf power reaching personnel could cause burns or tissue damage. However, rf power at LANSCE is always contained within conducting surfaces. (Also, equipment protective systems are likely to shut power off if the rf transmission lines are not correctly assembled.) LANSCE and ESH-5 technicians survey rf power systems at turn-on and after maintenance to ensure that exposure limits specified by ANSI C95.1 are not exceeded. Known rf leaks are enclosed with physical barriers. The victim’s reaction to the burn stimulus would also limit the hazard severity.

If work with exposed rf hazards is necessary, temporary barriers are used and the job is governed by SOPs or SWPs.

4.3.3 Lasers

Laser systems are widely used in the experimental programs. All laser systems are operated according to LANL standards as well as ANSI Z136.1 and all laser SOPs and laser installations must be approved by the LANL laser safety officer.

4.3.4 Magnetic Fields

Magnetic fields up to 16 kilogauss extend into spaces accessible to the whole body, and up to 25 kilogauss accessible to the hand, at some times and in some places on site. More common are stray fields in the 10–100 gauss range. While health risks from magnetic fields are not well understood, there is a particular hazard to persons with pacemakers. High magnetic fields especially around large superconducting magnets may also present safety hazards from the forces they exert on iron objects such as tools and gas bottles.

Personnel exposure to magnetic fields is controlled both by engineering and administrative controls as set forth in AR 5-3. Surveys of magnetic fields are performed by ESH-5 and warning signs are posted for areas where these fields may exceed 5 G (the exposure limit for personnel wearing cardiac pacemakers).

Employees who either work in or enter these areas receive job-specific training. Use of large magnets is controlled by individual SOPs.

4.4 HAZARDOUS MATERIALS

Facility operation and research activities involve storage, transport and handling of hazardous materials typical in laboratories. These operations follow federal and LANL standards. Hazards present include flammability, cryogenic burns, toxicity, and oxygen deficiency. Cryogens, gases, liquids, and solids are discussed in that order.

4.4.1 Hazardous Materials Quantities

Table 4-9 lists the hazardous materials, and their quantities and locations, normally in use in LANSCE. A discussion of the handling and control of these materials follows.

Table 4-9. Hazardous materials used at LANSCE.

Material	Quantity	Where Used	Hazard
Cryogens			Cryogenic burns
LH_2	8 *L*	MLNSC Target 1	Flammable & explosive
LN_2	100 *L*	ER 1	ODH, cryo. burns
He	100 *L*	ER 1	ODH
Gases			
Hydrogen	20 scf D-size cylinders-several	Injector	Flammable & explosive
	2200 scf in H-size cylinders	Outside ER1	“
Nitrogen	28 kscf high-pres. tube trailer	Outside	High pressure, ODH
Helium	28 kscf high-pres. tube trailer	Outside	High Pressure
Acetylene	20 scf cylinders	Injector	Flammable
Oxygen	2200 scf cylinder	Welding	Fire accelerant
Argon	2200 scf cylinder	“	ODH
Sulfur hexafluoride	300 scf	Injector	ODH, toxic byproducts
Mercury	3625 kg	ER1	Toxic
Solvents (acetone, ethanol)	Less than 1-*L* containers in labs, 55-gal drums outside	Degreasing	Toxic, flammable
NaOH	55-gal. drum	A6 air scrubber	Caustic
Lead	As required	Shielding	Toxic
Cesium	120 g in 20-g ampoules	Injector	Toxic, flammable

4.4.2 Cryogens

Liquid nitrogen is used for cryogenic pumps, cold traps on leak detectors, pre-cooling in liquid hydrogen systems, and in experimental apparatus. In superconducting magnets the container quantity can be over 100 liters. Up to 500 liters of liquid helium is used in superconducting magnet reservoirs, and dewars of 100 L and 500 L are used routinely. Liquid hydrogen is used in the MLNSC hydrogen moderator system.

Supercooled liquids and surfaces can cause cryogenic burns. Barriers to this hazard include minimizing personnel exposure through use of cryogenic containers and insulation, proper handling, training, and PPE.

LN and LHe are latent oxygen deficiency hazards because they evaporate readily and dilute or displace breathable air. The potential for ODH due to trapped gases in enclosed spaces is part of the review process for use of cryogens. ODH is discussed below.

4.4.3 Hydrogen

The MLNSC hydrogen moderator system (Figure 4-4) contains about 8 liters of liquid hydrogen at up to 180 psi (1.24 MPa pressure; additional bottles of hydrogen gas are

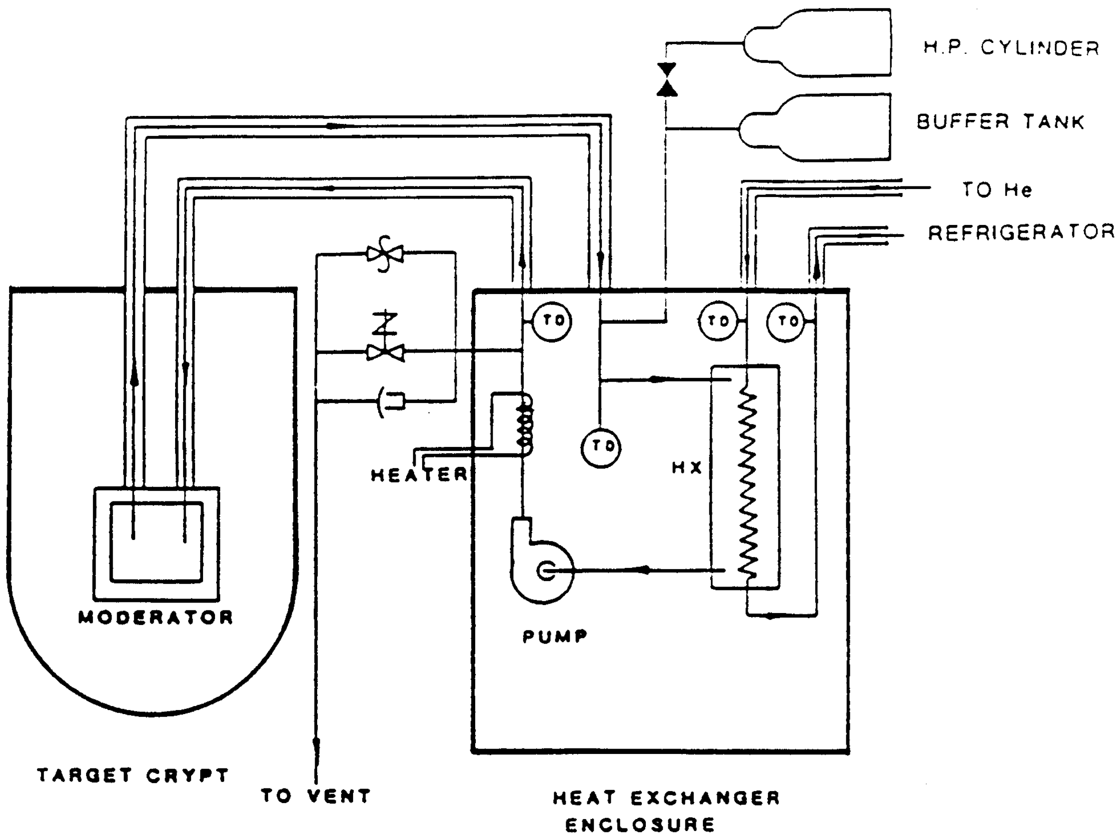

Figure 4-4. Hydrogen moderator system for MLNSC.

stored outside the building. The injectors, in Sector J, each use one size-D (20 scf) cylinder; a few spare bottles are stored outside. Experimental equipment will sometimes use hydrogen in small quantities.

Hydrogen is a flammability and explosive hazard. The combustible mixture range for hydrogen in air is 4–75% by volume; in this range, it can burn, deflagrate, or combust if confined. Barriers to this hazard include engineered containment, limitation of quantity, ventilation, training, and procedures.

The largest significant releasable volume in use is in the MLNSC hydrogen moderator system. This system is continuously monitored by internal pressure instrumentation, combustible gas detectors in the Target Service Cell and Service Area, and vacuum sensors in the target crypt and vacuum jackets. Prolonged power failure or any indication of a leak or over-pressurization of the system will automatically vent the system through a separate, dedicated stack designed to withstand any possible combustion pressure.Considering the volume of the target Service Cell and Service Area, loss of all of the system hydrogen into either room could not form a flammable mixture if the hydrogen were distributed throughout the enclosure. However, it is possible for limited combustion to occur at the site of a leak or at the mixing front if hydrogen is lost. The following conditions result in automatic emergency shutdown and venting of the MLNSC hydrogen system:

- Loss of crypt vacuum above 10 torr;
- Drop in hydrogen pressure, indicating a possible leak;
- An electric power outage lasting longer than six minutes;
- Loss of insulating vacuum in a transfer line or the cryogenic heat exchanger enclosure;
- Hydrogen over pressure above 200 psi (1.38 MPa) or failure of rupture disc;
- Detection of combustible gas in either the Target Service Cell or Service Area; or
- Helium refrigerator compressor shutoff.

Detailed procedures are specified in a LANSCE SOP for purging and trouble shooting the system after an emergency vent, prior to recharging. Specially trained personnel are on call by radio pager 24 hours per day when the hydrogen moderator system is in operation.

Occurrence of a limited hydrogen fire depends on an initiating event combined with human error or mechanical failure resulting in a leak during routine gas bottle handling, plumbing repair, or system purging.

Main bottle storage is outside, normally valved off; the quantity of hydrogen within the enclosed system is far less than that required to reach the lower explosive limit, a 4% hydrogen-air mixture ratio, considering the large room volume. Simultaneous presence of free hydrogen and air in the target crypt is prevented by the automatic dump system, and available crypt volume is very limited.

4.4.4 Other Materials

4.4.4.1 Sulfur Hexafluoride

Sulfur hexafluoride is used as an insulator in the injector high-voltage columns and requires handling as a hazardous material because of the potential for asphyxiation and the toxicity of breakdown products at elevated temperatures. It is not toxic at room temperature as used in injector operations. An SOP is used for emptying and filling the columns with SF_6. Approximately 100 ft^3 of the gas, which is five times heavier than air, is contained in each of three acrylic jackets. The asphyxiation potential if the entire quantity in the three columns were released at once has been evaluated and found not to represent an oxygen deficiency problem (Wilton 1992, Ryan 1993). Most of the SF_6 would settle to the bottom of the basement where it would rise to a level of less than two inches. Mixing of the SF_6 with the room air would be minimal.

4.4.4.2 Mercury

In Experiment Room 1 at MLNSC, 10 neutron shutters that utilize liquid mercury are imbedded in the Target 1 shield. These shutters are individually controlled to allow access to Target 1 neutron flight paths during beam delivery to MLNSC, without having to interrupt operations on the other flight paths. They also serve to shield against residual target activity during maintenance periods. The shutters are an integral part of the Instrument Personnel Safety System (IPSS) for each flight path. Figure 4-5 shows the schematic layout of a typical shutter.

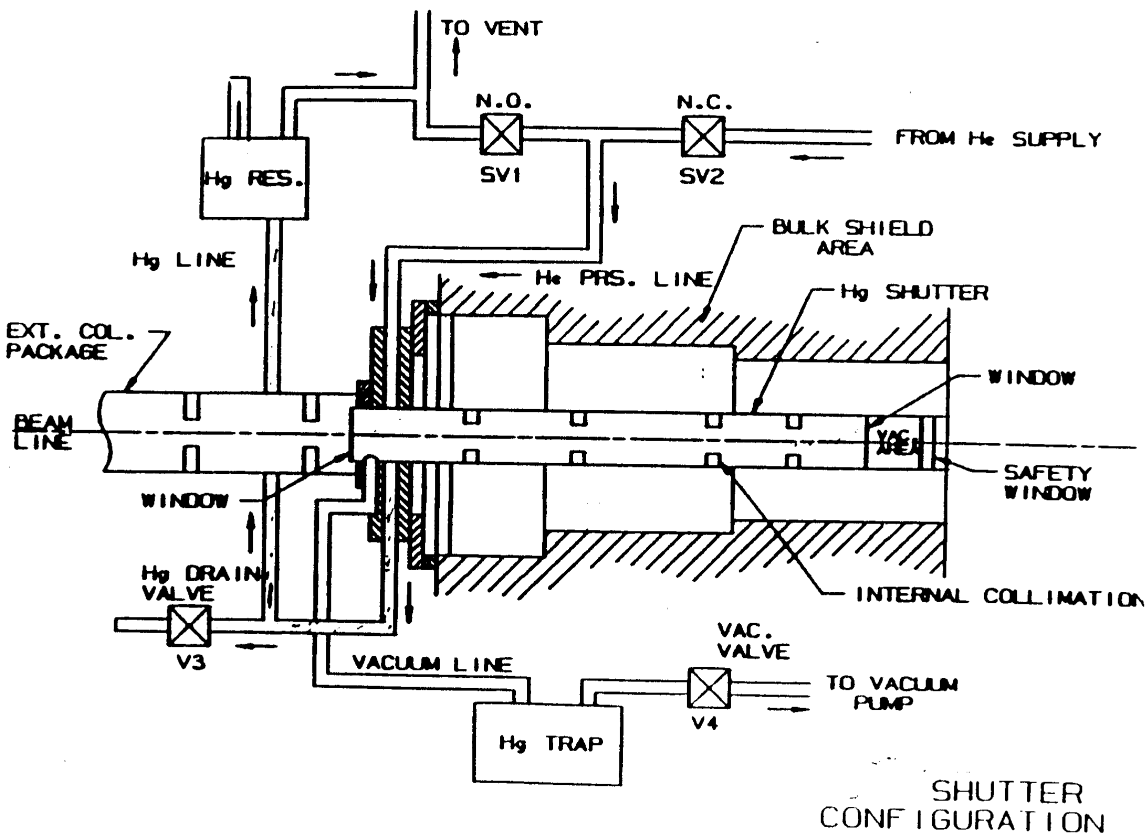

Figure 4-5. Schematic diagram of MLSNC mercury shutter

Mercury was chosen as the shielding medium for these shutters because of its high density and its liquid state, which allow simple, fail-safe, gravity-driven shutter closure mechanisms. The total amount of mercury used in the system, including reservoirs, overflow tanks, and minimal spare storage, is 3625 kg. Interaction between shutters can only occur by vapor transfer, so any given mechanical accident (ruptured line, broken fitting, inadvertent release during maintenance) exposes only about 10% of the total mercury to release. The lowest point of each shutter plumbing network is an overflow reservoir sized to hold all of the mercury in that network.

Activation of mercury in the shutters does not present a significant increment of hazard to operations at MLNSC. The radioisotopes produced by neutron absorption, and to a lesser degree by spallation, are soft γ and β emitters of relatively short half-life; mercury is an excellent shielding material for such radiation, so it is self-shielding except for emissions from very near its surface. Thus, precautions for handling, storage, and final disposal of mercury used in these shutters are dominated by its chemical properties.

Heavy carbon steel is used for reservoirs, but other components such as tubing and fittings are made of stainless steel. Aluminum is specifically avoided unless it is clad by a material resistant to amalgamation. After a few kilogram-size spills during early system development, system leakage has been limited to a few grams per year. Specific procedures for identification, isolation, and control of spills, are published in the "LANSCE [MLNSC] Operating Instructions," required reading for all persons at MLNSC.

Long-term exposure to mercury vapor has been virtually eliminated by keeping the system fully enclosed, vented only through an adsorber bed located in the Service Area above ER-1. The helium pressure system used to drive mercury from the shutters is also closed except for venting through that same adsorber, and is triply protected against over pressure that might rupture a shutter window. Some exposure to indoor atmosphere does occur during draining and refilling associated with maintenance, or potentially, after an accidental spill.

Complete, detailed procedures for system management are specified in an MLNSC SOP. Only designated, specially trained persons are allowed to work on the mercury shutter system; protective equipment such as rubber gloves, booties, plastic bags, sulfur, and a mercury vacuum cleaner are kept in a special segregated mercury system storage cabinet near the shutters.

Group ESH-5, the Industrial Hygiene Group, provides field surveys to determine the presence and extent of potentially harmful agents, including mercury, in the workplace. They also provide consultation prior to planned operations and in an emergency, such as advice on containment and cleanup and measurement of residual mercury vapors. If respirators are needed, ESH-5 can supply and fit them to individual employees.

Group ESH-1, the Health Physics Operations Group, conducts frequent surveys of the experiment areas and monitors all items removed from radiation areas for contamination. ESH-1 also operates a facility for decontaminating mercury. Group CST-17, the Waste

Management Group, has facilities for disposal of hazardous chemical wastes, and is responsible for safe disposal of any mercury released from MLNSC.

4.4.4.3 Solvents

The kinds and quantities of solvents used at LANSCE are similar to those generally found in heavy laboratories. Several workshops have acetone and alcohol in amounts on the order of 1 liter. Non-hazardous solvents are used when possible. Larger quantities of solvents are kept in 55-gal drums located outside the buildings. The use, storage, and labeling of solvents are in accordance with AR 6-1, “Chemicals.” Waste solvents and solvent-contaminated rags are stored in authorized satellite waste storage areas. The facility waste management coordinator arranges for disposal of these wastes through Group CST-17.

4.4.4.4 Polychlorinated Biphenyls (PCBs)

PCBs were widely used in site electrical equipment. A program to find and eliminate, where possible, PCBs was completed several years ago. All equipment containing oil is marked for level of residual PCB contamination, if any. Oil spills receive rapid response from ESH Division and are treated appropriately.

4.4.4.5 Lead

Lead shielding is used in many places onsite. Lead is a toxic metal; therefore, gloves are used to handle it. An inventory is stored in the “Lead Shed,” a remote, locked building near the east end of TA-53.

4.4.4.6 Cesium

Cesium is used in the H^- ion source to enhance the production of H^- ions. Cesium vapor condenses on the cool surfaces of the source. Cesium is handled as a hazardous material. The ion source is back-filled with argon, but when it is opened to the air, moisture in the air reacts with the cesium to form gram amounts of cesium hydroxide (CsOH), a corrosive and flammable material. Trained, experienced personnel transfer cesium into the ion source according to an SOP. ESH-5 periodically monitors cesium operations and recommends proper personnel protective equipment.

4.4.4.7 Sodium Hydroxide

Sodium hydroxide is used in a caustic bath in the Area A exhaust air scrubber.

4.4.4.8 Other Chemicals

Chemicals other than solvents, such as adhesives and paints, are stored in manufacturer's containers or other approved containers throughout the facility. ESH-5 evaluates the use of personal protective equipment used in the handling of chemicals. Chemicals are handled in accordance with the MSDS (Materials Safety Data Sheet) provided by the manufacturer, and disposal is conducted by Group CST-17. MSDSs are maintained by individual groups at locations near chemical use areas. Spill response is conducted by the LANL Emergency Management and Response Group (FSS-20).

4.5 INDUSTRIAL HAZARDS

Many normal industrial hazards are found at LANSCE and are managed similarly with conformance to national codes and standards. With these measures in place, the risks are generally understood and accepted. Hazards discussed in the following sections include load lifting and movement, workspaces and confined spaces, and pressure and vacuum vessels.

4.5.1 Crane Lifts

Crane operation presents a hazard principally from elevated loads. The potential for dropping a load risks expensive equipment, personnel injury, and facility damage. Cranes, hoists, and other overhead lifts are available throughout LANSCE and are used almost daily to move equipment and shielding.

The risk of personnel injury is minimized by keeping loads low when possible and by choosing a path of movement such that equipment and people are not under a load as it is hoisted or positioned. Crane operators are trained and licensed by certified instructors and receive certification, hands-on training and on-the-job training. Access to crane and hoist controls is controlled by locking out pendants and radio control boxes so only qualified operators can operate cranes and hoists. Crane, hoist, and rigging operations are conducted according to AR 13.2 and applicable DOE Orders and OSHA standards.

Rigging is inspected on a regular basis and documentation for all rigging is maintained. These inspections include a visual inspection of each rigging component before it is used and an annual inspection that includes physical measurements of rigging parts. Inspectors are trained in inspection procedures and documentation of their training is maintained according to AR 13.2 and applicable DOE Orders and OSHA standards.

Specific procedures for crane operations that are considered out of the ordinary are implemented for each of these operations. These "critical lifts" are based on load weight, equipment expense, lift complexity, and load radioactivity levels. Special planning sessions are included in the procedures addressing critical lifts. These sessions occur before and after the operation, and if problems arise, during the operation.

Before each critical lift, the crane and rigging is inspected, including the critical electrical, electronic, and mechanical systems. The crane operators are verified as having the proper training, and follow the standard/safe operating procedure (SOP). Some cranes are operated remotely, so, should a radioactive load be dropped, there is no immediate danger to the crane operator. The steps to be taken to recover the load and to retrieve the contamination, if any, are carefully thought out and implemented only when it is assured that the job can be done safely. To retrieve the dropped load, and to clean up the contamination, if any, the mitigating measures used to reduce the radiation dose given to personnel include the use of shielding and remote handling techniques, if needed.

If a power failure occurs when a radioactive component is being lifted with an overhead crane, the crane is shut off to prevent any sudden movement when power is restored. Also, the area around the radioactive load is roped off to prevent radiation exposure to personnel. Mitigating measures used to reduce the personnel radiation dose include the use of shielding and remote handling techniques. To reduce exposure and contamination, highly activated components moved from target cells are placed in shielded casks when possible before they are moved out of the target cell.

4.5.2 Forklifts

Forklift operation can present hazards from equipment movement and elevated loads. Forklifts from one to thirty ton capacity are used at LANSCE. They are powered by battery, liquid propane and gasoline engines, and diesel engines. All forklift operators are licensed for the capacity of the forklift they are operating and are trained and certified according to AR 13.10 and applicable DOE Orders and OSHA standards. Several forklift accidents have occurred over the years at TA-53, none resulting in significant lost-time injuries.

4.5.3 Workspace

Workspace safety, including protection from tripping and falls, is monitored by line and safety management on a continuing basis. Group ESH-5 provides Laboratory expertise for Industrial Hygiene.

4.5.4 Confined Spaces

All work in confined spaces is conducted in accordance with AR 8-1 and applicable DOE Orders and OSHA standards.

4.5.4.1 Oxygen Deficiency Hazard

ODH may occur in poorly ventilated areas. The onset can be rapid with release of liquified gases. These locations are few at LANSCE and have appropriate posting, access controls, and alarms.

Poorly ventilated areas include the IP pit, REF cave, and the Line B target cave. Safety review of cryogens always involves ODH review.

4.5.5 Pressure and Vacuum Systems

Pressure vessels are regulated under AR14, which requires these vessels to meet national code or special laboratory review, and provides many controls on use and maintenance.

Vacuum vessels have an implosion energy limited to the equivalent of 1 bar of overpressure and thus represent a relatively low hazard. However, the large volume of the accelerator vacuum system means that implosive release is capable of causing some injury and extensive equipment damage. Therefore beam lines are segregated by fast-acting valves designed to limit the extent of damage caused by a breach of the vacuum envelope. During maintenance, valves are used to segregate sections of the system, thus reducing section volume. Access to thin windows is normally limited by their installation within shielding, housings, etc., but if they are otherwise accessible, safety screens or covers are used.

4.6 FIRE

This section contains a discussion of fire hazards, fire protection, administrative controls, and life safety.

4.6.1 Description of Fire Hazards

LANSCE accelerator and experimental facilities are built of metal and concrete and contain relatively small quantities of combustible materials. Electrical cables and the high-flash-point dielectric oils used in capacitors and rf power sources (most of the latter are located in the linac equipment aisle) constitute the most significant source of combustibles permanently in place. Small amounts of solvents, some flammable gas cylinders, and other materials constitute localized hazards. Fire barriers, consisting of walls and doors of appropriate construction and ventilation dampers, are part of the construction. A Laboratory review process is in place to ensure that facility modifications do not compromise these features.

A liquid hydrogen cooling system is used in conjunction with the MLNSC target (Target 1). The fire hazard associated with this system is addressed in Section 4.4.3.

4.6.2 Fire Protection

The Laboratory has a fire protection program to minimize personal injury, property damage, and operational delays caused by fires. The fire protection program is jointly administered by the Facilities, Security and Safeguards (FSS) Division and the Environment, Safety and Health (ESH) Division. The fire protection requirements, described in AR (Administrative Requirement) 11-2, are based on NFPA standards and DOE orders. Fire detectors, alarms and protective systems for LANSCE have been previously described in Section 3.3.4.

4.6.3 Administrative Controls

Operating groups and the LANL Fire Protection Office provide administrative controls as specified by AR 11-2.

4.6.4 Life Safety Code

Laboratory policy requires that occupants of any Laboratory building be able to evacuate safely and promptly in the event of fire or other emergencies, as described in ES&H Administrative Requirement AR 11-1. For the purposes of life safety, LANSCE facilities are classed as industrial occupancies with “ordinary” hazard of contents (NFPA 101). The design of the facilities dates to the mid-1960s. Though the Life Safety Code has changed since then, the changes have not significantly impacted the adequacy of the life safety features of these buildings.

Most buildings are equipped with multiple exits. Structures with one exit, such as the MPF-3 Sector P dome and the WNR “Blue Room” (both experimental areas) are normally unoccupied, or normally occupied by fewer than ten persons during maintenance or experimental support activities.

Building exits and, where required, access to exits, are marked by approved, illuminated, readily visible signs. Commercially available battery-operated emergency lighting units illuminate means of egress in the event of power failure. The emergency lighting units are maintained by the Laboratory's support services contractor.

The linac building contains a number of vertical openings in the form of service shafts and hoist shafts from the underground beam tunnel to the equipment room/aisle at grade level. The underground beam tunnel is constructed of concrete and contains no combustibles except electrical cable insulation and very small quantities of pump oil. The waveguide shafts are filled with sand for the purpose of radiation shielding. The hoist shafts are isolated by fire doors at the beam tunnel and equipment aisle levels. The equipment room/aisle has multiple exits in each sector and is normally unoccupied except during maintenance or operational support activities.

In Experimental Area A, the largest structure in the complex (MPF-3, Sector M), the longest travel distance from a potentially occupied area to an exit door is approximately 350 feet. (This distance was measured from a power supply platform on the north side of the bulk shielding near the 23 foot level to either the southwest floor-level exit door or the northwest floor-level exit door in the adjacent staging area). At normal walking speed, approximately 90 seconds are required to traverse this distance. LANL guidelines specify that no more than 2.5 to 3 minutes should be required for a building evacuation. It is possible that a fire could occur in an experimental cave having a single exit and temporarily block the exit. This is analogous to a fire in an office or small laboratory with a single exit. However, the caves are open at the top to the large volume of the experimental hall, practically eliminating the possibility of smoke accumulation. Because of the nature of the materials in the accelerator experimental areas, a fire would most likely be of short duration (flammable gases, solvents) or smoldering (electrical cables), and would not involve the cave or building construction. Personnel should be able to take shelter in place at the opposite end of a cave until the exit path is open.

The underground Line D tunnel is approximately 550 feet long. During maintenance periods when the tunnel is most likely to be occupied, exits are available at both the north and south ends. There is also an exit into the PSR near the midpoint. Combustibles in the tunnel consist almost exclusively of cable insulation.

4.7 NATURAL PHENOMENA HAZARDS

Natural phenomena hazards can result from earthquakes and storms. Since TA-53 is located on a mesa top, flood is not a credible hazard. In accordance with the graded approach of DOE 5480.28, LANSCE facilities are considered to be in PC 2.

4.7.1 Seismic

The 1,000 year earthquake at Los Alamos is dominated by the background earthquake, while the 10,000 year earthquake is a maximum event of magnitude 7 on the Pajarito fault (see Figure 3-5). Effects of the 1,000-year earthquake at LANSCE are judged to present no unusual risk to the public, the environment, or workers (see Section 3.2.9.2).

The projected 10,000 year earthquake could have a significant impact on structures, systems, and components (SSCs). Equipment damage is likely and harm to personnel could result if support structures for overhead equipment such as cranes or cable trays fail, or if shielding blocks overturn. Highly activated targets and beam stops are enclosed within thick bulk shielding, and it is unlikely that this shielding would be breached enough to cause a personnel hazard from direct radiation. If a building or structural components collapsed around a beam stop or target, the activated material could not be removed for some time, but its entombment would not pose a risk to the public or environment in the interim. Rupture of activated cooling water systems could result in contamination within buildings, but containment by the building and the large separation from the water table through dry tuff prevents risk to the environment.

A significant seismic event can be expected to cause a loss of power and vacuum in the accelerator or beam transport lines, terminating beam delivery.

4.7.2 Wind Loading

The probability of a tornado at this location has been estimated to be less than 10^{-6} per year, but strong winds do occur (Figure 3-7). The wind criteria in DOE STD 1020 for PC 2 SSCs is 77 mph with an importance factor of 1.07. The annual exceedance probability associated with PC 2 is 2×10^{-2}. The design wind loading for the worst case structure, MPF-3 Sector M, was 25 psf. Calculations done by FSS-6 in accordance with DOE STD 1020, as referenced by DOE 5480.28, indicate that this building would withstand 16.10 psf. The probability of a wind loading accident is therefore extremely unlikely.

4.8 SAFETY HISTORY

Routine beam delivery for programmatic purposes began in 1973. Therefore, 23 years of operational safety experience is available. No radiation exposures beyond regulatory limits have been recorded.

Several incidents of loss of control of radioactive materials have occurred. Recently, some of these have been associated with improvements in detection sensitivity and involved extremely small quantities of material. No significant personnel exposures have resulted. An outstanding achievement of the radiological control program is the success in meeting or surpassing ambitious ALARA goals in doses received during maintenance operations. Overall, a several-fold reduction (factor of 4–10) among the various groups) in exposure to operational maintenance workers has been achieved since 1989, and typically only one or no worker exceeds a 0.5 rem annual dose.

Although LANSCE lost-workday record is exemplary, injuries from routine laboratory and industrial hazards have occurred. Incidents requiring overnight hospitalization have occurred at the rate of one per several years. Recent cases included hearing damage and minor burns from a hydrogen conflagration.

Significant property damage incidents, with single-incident value exceeding $200k, have occurred and have had substantial programmatic impact but no loss of worker safety.

The history of 5000.3 reportable occurrences at LANSCE is available since the reporting system was implemented. The bulk of these consist of administrative safety violations (near misses, discovered safety weaknesses) and minor losses.

4.9 SUMMARY—SAFETY ANALYSIS

The operations activities of LANSCE were analyzed for hazards, and the barriers, control measures, and mitigating factors in place were evaluated.

The hazard of prompt radiation in beam delivery areas is managed by shielding and access controls. These are implemented according to accepted standards and practices which experience shows make the risk very low. Adjacent to beam delivery areas, the hazard is very localized and is managed by special access rules and instrumentation. The quality of the controls is monitored through regular performance checks, annual assessments, and personnel and spot dosimetry records.

Hazards from radioactive materials are managed by historically well-developed practices including access controls, remote handling, and careful work practices. The quality of the controls is monitored through personnel and workplace dosimetry records and a sensitive automatic site exit monitor. Air emissions are managed and monitored.

Hazards from electromagnetic energy can be high and range over a wide spectrum, and are managed according to well-developed industrial practices and Laboratory procedures.

Other hazards such as fire, hazardous materials, non-ionizing radiation, rigging and lifting, confined spaces, and pressure systems were also reviewed. Control of common workplace hazards by specific codes and regulations is assumed adequate.

The conclusion of this analysis is that the hazards at LANSCE are adequately managed, and that the residual risks from LANCSE facility operation are low.

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[1] See Index by Document Number, http://iosun.lanl.gov:2001/htmls/policy/esh/indexdoc.html

[2] 53FMS 107-01.0 Prompt Radiation Protection (effective date 01/01/96), see http://www.atdiv.lanl.gov/doc/aotfm/class1/fmtable.ht

[3] AL 5481.1B, Albuquerque Operations Office (January 27, 1988); see http://www.explorer.doe.gov:1776/htmls/directives.html.
Also see DOE-STD-3009-94 (July 1994) pp. 50-52, available through the same path.